Gravity driven deformation processes in the Bushveld Complex contact aureole, South Africa

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The 2.05 Ga, intrusive sill-like mafic and ultramafic Rustenburg Layered Suite (RLS) of the Bushveld Complex covers an area in excess of 65 000 square kilometres and has a vertical thickness of between 6 and 8 km. Linked to this is an equally extensive contact aureole that penetrates the sedimentary floor sequence of the Transvaal Supergroup to depths of between 4 and 6 km. The intrusion floor contact is largely conformable to the country rock layering but regionally transgresses the entire Transvaal Supergroup, resting on granite basement in the North. Post-emplacement subsidence of the Rustenburg Layered Suite has resulted in a large asymmetric basin with centripetal dips ranging from 5 degrees in the south to over 80 degrees along the northern margin which coincides with the Thabazimbi Murchison Lineament, a zone of crustal weakness along which subsidence was maximized.

The geometry of the floor contact was controlled initially by brittle fracture mechanisms resulting in a stepped and fingered intrusion front resulting in deformed interfinger zones and bridges (Clarke et al., 2000; Clarke et al., 2009). Magmas were emplaced within 65 ka (Cawthorn and Walraven, 1998) with the modeled contact aureole at the 550 ºC isotherm reaching its thermal maximum about 1 Ma later. As the contact aureole developed, the primary brittle structures were modified by ductile deformation processes and subsidence of the RLS. The most impressive and unique of these structures are diapiric domes that characterize the eastern contact aureole (Uken and Watkeys, 1997) (Figure 1). The domes formed by diapiric amplification of initial interfinger deformation zones associated with the earliest mafic-ultramafic pulse of the Bushveld Complex, driven by loading and heating of floor rocks by the overlying RLS. Diapirs are separated by approximately 30 km, are typically up to 8 km in diameter and in places have risen to the top of the RLS with heights of 6-8 km. Thermomechanical constraints indicate that diapir development was restricted to metamorphic grades above the 550 ºC isotherm in the contact aureole, corresponding to the fibrolite and migmatite zones of the contact aureole. The duration of the deformation was restricted to the prograde metamorphic path in the contact aureole and terminated once the diapirs froze within the crystallized RLS magmas.

Coupled thermomechanical numerical modeling (Gerya et al., 2003) has shown that diapirism was triggered by the lowering of viscosity in the Pretoria Group during contact metamorphism and the presence of initial anticlinal perturbations of at least 500 m amplitude. Model amplitudes exceeding 1000 m produced exaggerated mushroom-like diapir shapes, inconsistent with field observations. This explains why the most mature diapirs are restricted to the northeastern Bushveld Complex, where the Lower Zone of the RLS was both exceptionally thick and had a segmented floor contact. Deformation strain rates, assuming that the 550 ºC isotherm temperature was attained 1 Ma after the intrusion and calculated from strain analyses and dome geometry, are in the order of 10^{-14} s^{-1}, corresponding to diapiric uplift rates of 0.6 cm/yr.

Diapiric cores locally exhibit symplectic replacement of andalusite by hercynite and cordierite, which is modelled as a result of prograde decompression (Johnson et al., 2004). Away from diapirs, microstructures record a single progressive subsidence-induced deformation foliation. Porphyroblast-matrix relationships display both rotation and non-rotation with respect to the extensional foliation. Dips of preserved sedimentary laminations within porphyroblasts, range from horizontal to a maximum coinciding with the present-day dip. This indicates that matrix-decoupled porphyroblasts did not rotate during deformation, preserving horizontal bedding laminations, thereby recording the palaeo-horizontal. Porphyroblasts that remained coupled to the matrix preserve a dipping internal foliation, rotating passively with the surrounding rock mass during subsidence and the tilting of the contact aureole.

Large scale remobilization of the floor to the Rustenburg Layered Suite resulted not only in a foliated and deformed contact aureole but also modified and deformed the intrusion itself. Growth folds are locally preserved adjacent to the diapirs and large-scale slumping within the subsiding magma chamber is recognised as near layer-parallel shear zones with a strong L-fabric and AMS foliation and associated sheath folds (Clarke et al., 2005). Intrusive layers dragged up adjacent to rising diapirs are potential blind targets for near surface Critical Zone platinum and chromite reefs, as subsequent zones of the Rustenburg Layered Suite truncate the deformed Critical Zone sequence.

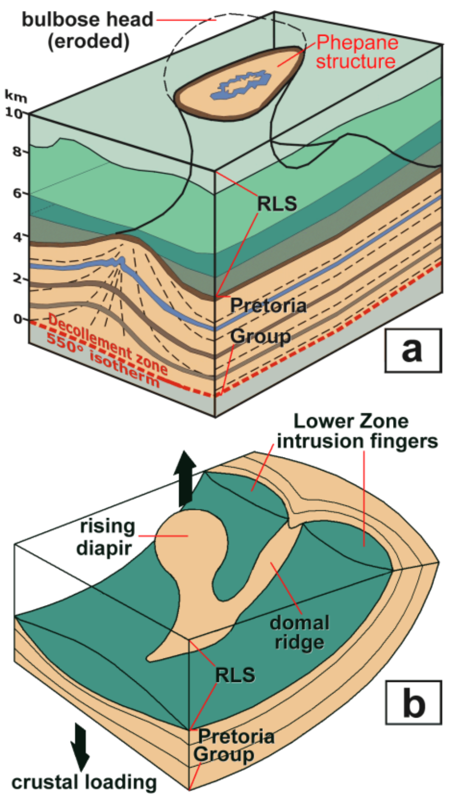

Figure 1. Model for contact aureole deformation below the subsiding Rustenburg Layered Suite of the Bushevld Complex.

a) Sketch of the Phepane mature diapir developed above a decollement zone in the contact aureole coinciding with the 550 ºC isotherm in the Pretoria Group argillites.

b) Schematic showing the initiation and growth of a contact aureole diapir from the interfinger zone of a fingered intrusion of the Rustenburg Layered Suite during gravitational subsidence.

References

Cawthorn, R.G. and Walraven,F. (1998). Emplacement and crystallization time for the Bushveld Complex. *Journal of Petrology*, **39**, 1669-1687.

Clarke, B.M., Uken, R., Watkeys, M.K., (2000). Intrusion mechanisms of the southwestern Rustenburg Layered suite as deduced from the Spruitfontein inlier. South African. *Journal of Geology*, **103**, 120–127.

Clarke, B.M., Uken, R., Watkeys, M.K., Reinhardt, J. (2005). Folding of the Rustenburg Layered Suite adjacent to the Steelpoort pericline: implications for syn-Bushveld tectonism in the eastern Bushveld Complex. *South African Journal of Geology*, **108**, 395-410.

Clarke, B.M., Uken, R., Watkeys, M.K., Reinhardt, J. (2009). Structural and compositional constraints on the emplacement of the Bushveld Complex, South Africa. *Lithos* **111**,21-36.

Gerya, T.V., Uken, R., Reinhardt, J., Watkeys, M.K., Maresch, W.V. and Clarke, B.M. 2003. Cold fingers in a hot magma: Numerical modeling of country rock diapers in the Bushveld Complex, South Africa. *Geology*, **31**, 753-756.

Johnson, T., Brown, M. Gibson, R. and Wing, B. (2004). Spinel-cordierite symplectites replacing andalusite: evidence for melt assisted diapirism in the Bushveld Complex, South Africa. *Journal of Metamorphic Geology*, **22**, 529-545.

Uken, R., Watkeys, M.K., 1997. Diapirism initiated by the Bushveld Complex, South Africa. *Geology*, **25**, 723–726.